Modeling activities related to NEWS, MAP and PMM

- GCE and GCE-LIS (MERRA provides forcing to derive CRM (diurnal variation)
- WRF and WRF-LIS (Snow event, hurricane/typhoon, MCS)
- MMF: Coupled fvGCM (GEOS4/5/6) and GCE-LIS (flood/drought, diurnal variation, MJO)
- Meso-scale GCM (tropical cyclone, hurricane, MJO)
- Satellite simulators (TRMM, GPM, Cloud-Sat, ACE)

Local <----> Global

Meso-scale

Goddard Multi-scale Modeling System with Unified Physics

Tao, W.-K., D. Anderson, J. Chern, J. Estin, A. Hou, P. Houser, R. Kakar, S. Lang, W. Lau, C. Peters-Lidard, X. Li, T. Matsui, M. Rienecker, B.-W. Shen, J.-J. Shi, and X. Zeng

NASA Goddard Space Flight Center

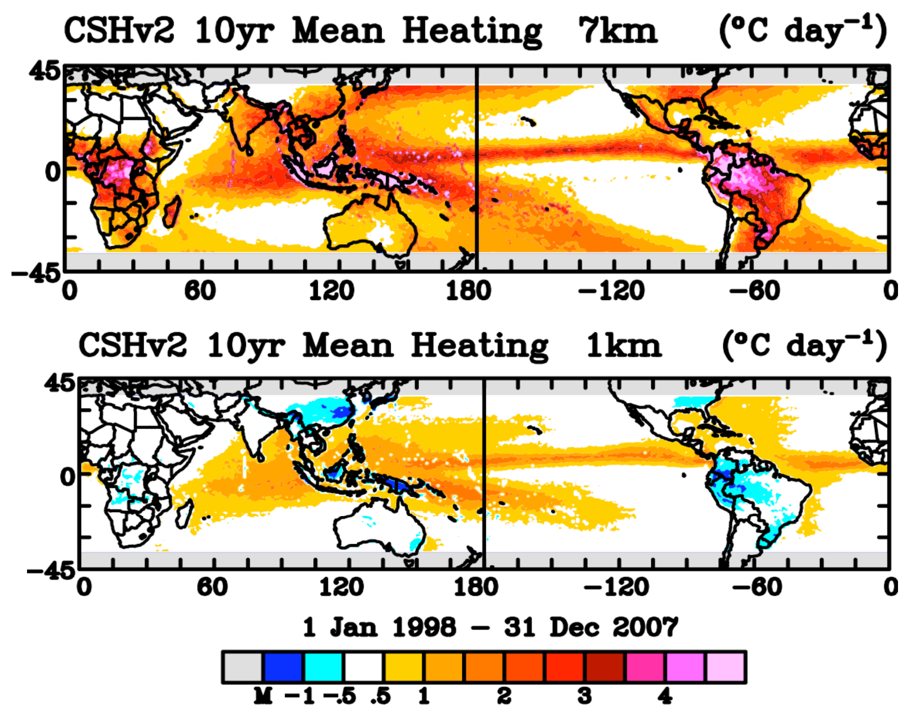
Greenbelt, MD 20771, USA

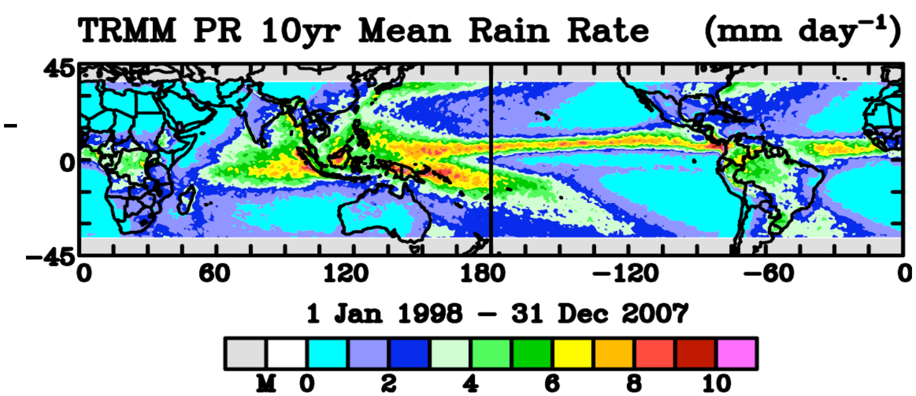
Tao, W.-K., D. Anderson, J. Chern, J. Estin, A. Hou, P. Houser, R. Kakar, S. Lang, W. Lau, C. Peters-Lidard, X. Li, T. Matsui, M. Rienecker, M. R. Schoeberl B.-W. Shen, J.-J. Shi, and X. Zeng, 2009: Goddard Multi-Scale Modeling Systems with Unified Physics, *Annales Geophysics*, **27**, 3055-3064.

Tao et al. (2009, J. Climate) <---------

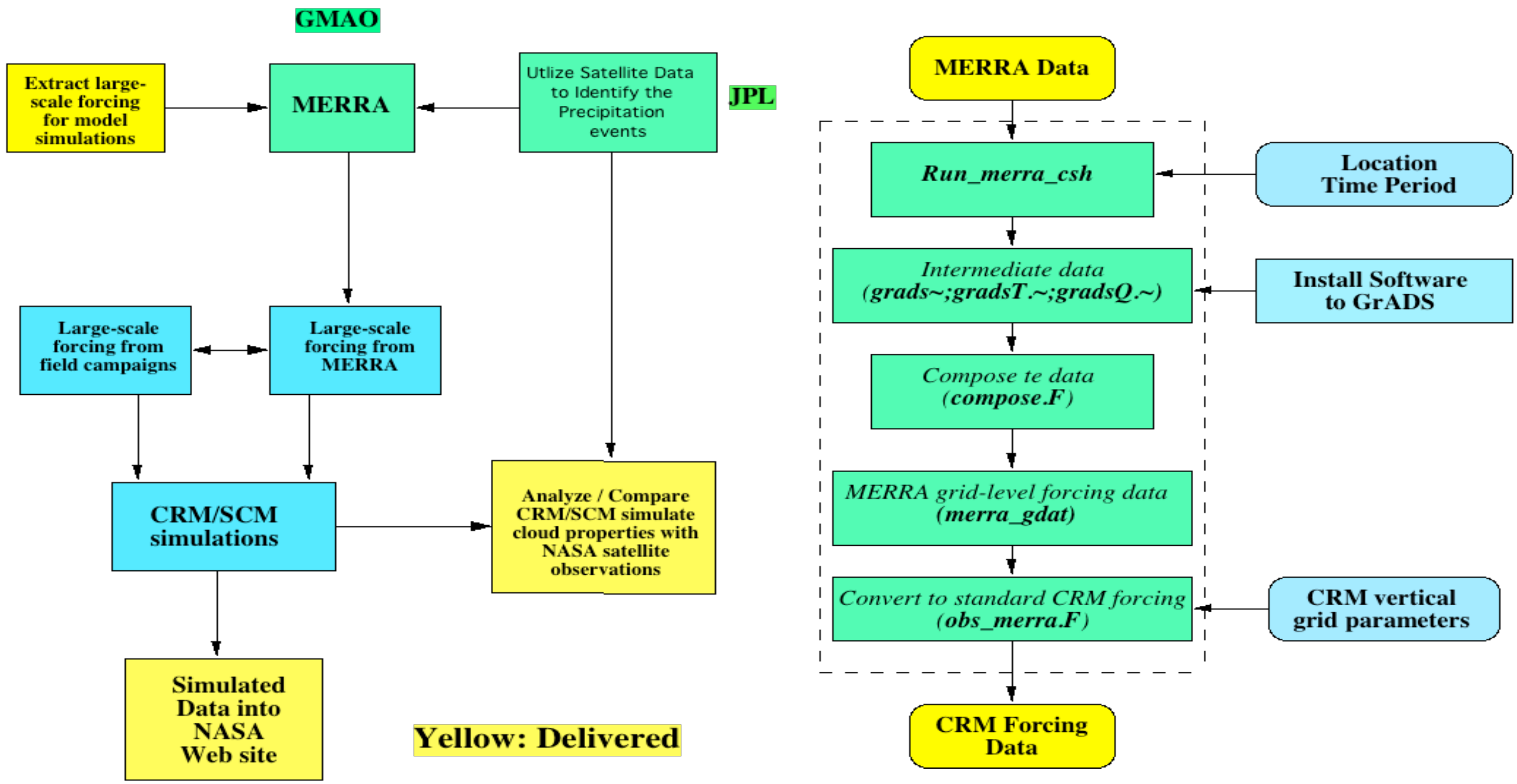
Comparison with MERRA/ERA40

CSH retrieved Q_1 - 10 Year Climatology





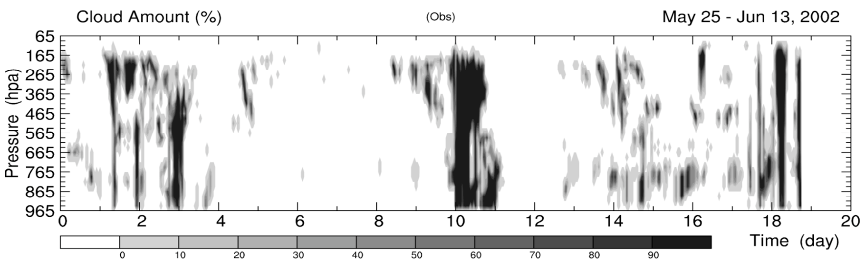
Coupling MERRA and CRM to study the cloud and precipitation processes

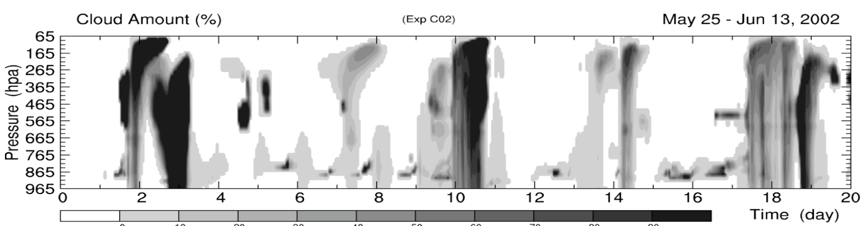


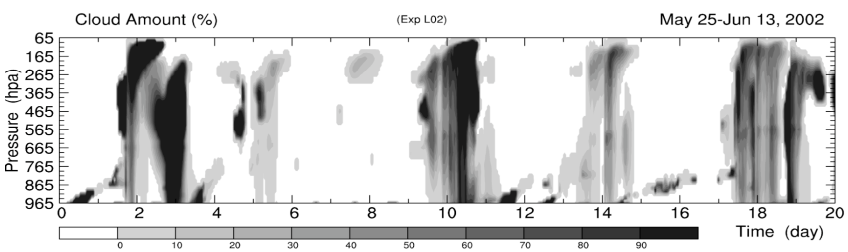
Tao, I.-D. Choi, X, Zeng, S.-K. Kang, M. Rienecker

GCE-LIS and WRF-LIS Coupling System

LIS impact on GCE cloud amount



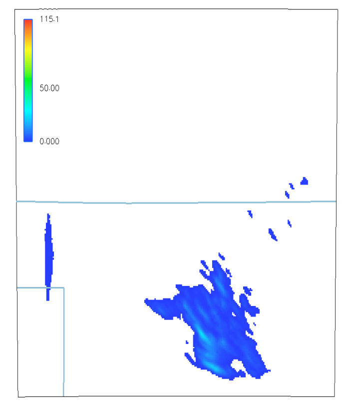




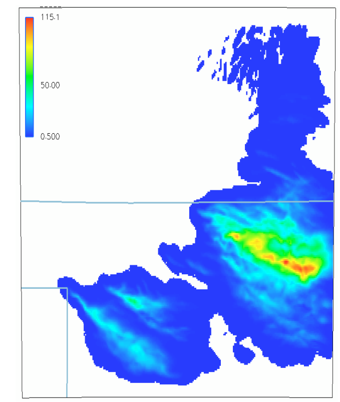
Twenty-day cloud simulation is done in Oklahoma in 2002 and its cloud amount is evaluated with ARM observations. Upper panel shows observed cloud amount. Middle and low panel modeled cloud amount with ARM and LIS surface fluxes as input, respectively. The results from numerical experiment with LIS capture observed cloud and precipitation processes especially for less-organized convective clouds. Adapted from *Zeng et al*. [2007].

LIS Spin-up Impact on WRF+LIS Precipitation

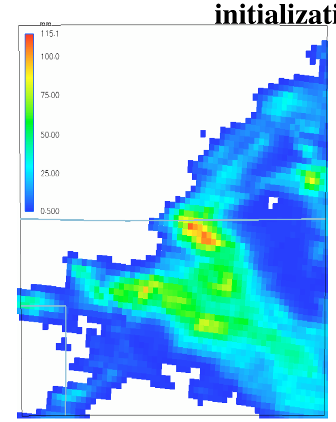
Scientific Evaluation: June 12 IHOP Case



24 hour accumulated precipitation with default soil initialization



24 hour accumulated precipitation with LIS 7.5 year spin-up soil initialization

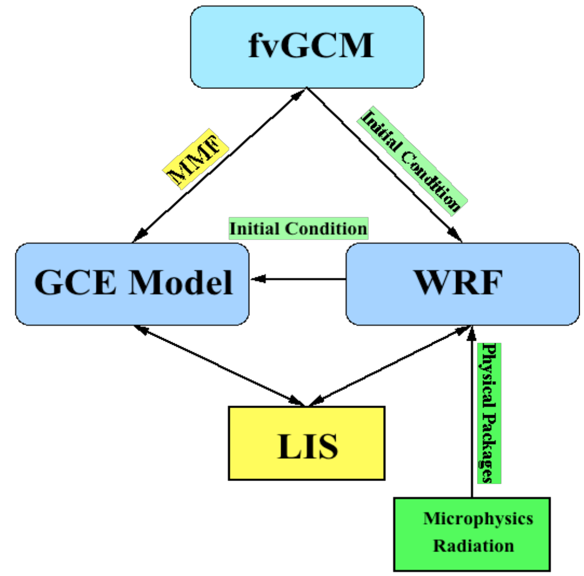


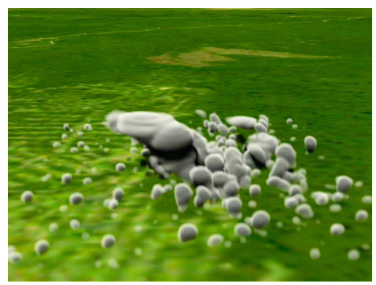
Observed Radar Derived Surface Precipitation (Source: NOAA/NCEP)

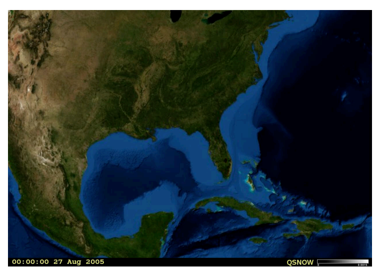
Goddard Multi-scale Modeling System with Unified Physics

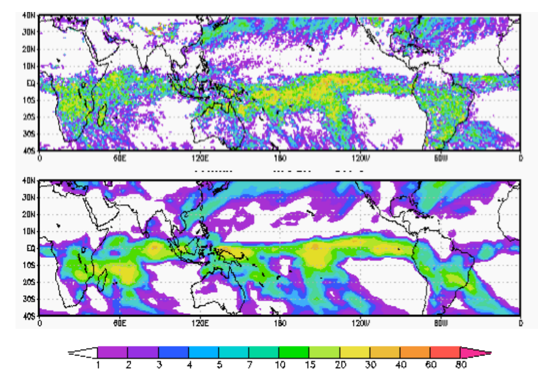
Recently, a multi-scale modeling system with unified physics was developed at NASA Goddard. It consists of **(1) the Goddard Cumulus Ensemble model (GCE), a cloud-resolving model (CRM), (2) the NASA unified Weather Research and Forecasting Model (WRF), a region-scale model, and (3) the coupled fvGCM-GCE, the GCE coupled to a general circulation model (or GCM known as the Goddard Multi-scale Modeling Framework or MMF).** The same cloud microphysical processes, long- and short-wave radiative transfer and land -surface processes are applied in all of the models to study explicit cloud-radiation and cloud-surface interactive processes in this multi-scale modeling system. This modeling system has been coupled with a multi-satellite simulator for comparison and validation with NASA high-resolution satellite data. The left figure shows the multi-scale modeling system with unified physics. The GCE and WRF share the same microphysical and radiative transfer processes (including the cloud-interaction) and land information system (LIS). The same GCE physics will also be utilized in the Goddard MMF.

The idea to have a multi-scale modeling system with unified physics is to be able to propagate improvements made to a physical process in one component into other the components smoothly and efficiently.





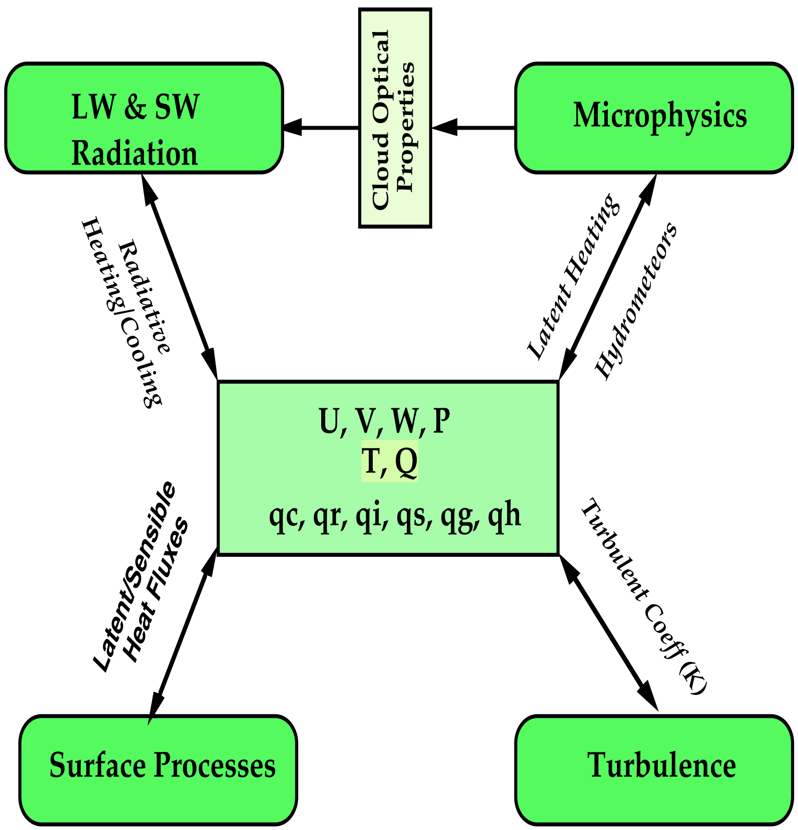




Left-upper panel shows the GCE high-resolution (250m) simulated a South American MCS.
Left-lower panel shows the WRF (1.67 km) Hurricane Katrina (2005) simulation.
Right-upper panel shows the MMF simulated and TRMM observed rainfall.

Goddard Cumulus Ensemble (GCE) Model (1982-Present)

(Tao and Simpson, 1993; Simpson and Tao, 1993;Tao 2003; Tao et al. 2003)



Unified GCE V. 1 (FY10)
Document will be available soon

2D/3D ***Anelastic or Compressible***
Close or Open Upper, Cyclic or Open Lateral B.C.

Microphysics: 13 different schemes
(Warm rain, 3ICE, 2-moment 4-ICE; spectral-bin scheme allowing cloud-aerosol-precipitation interactions) - ***RAMS'2-moment***

Positive definite advection scheme: Scalar variables (cloud species)

Stretched Grid: Horizontal and vertical

Radiative transfer model: Efficient - explicit cloud optical properties and aerosol direct effect

Land surface models: Land Information System ***(LIS) and PLACE*** - 1 km land characteristics

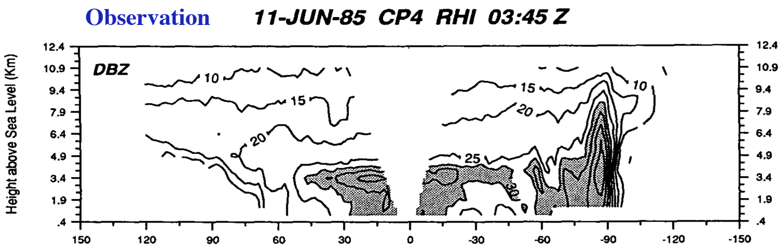
Ocean mixed layer model

MPI (Juang *et al*. 2007): 100-100,000 CPUs

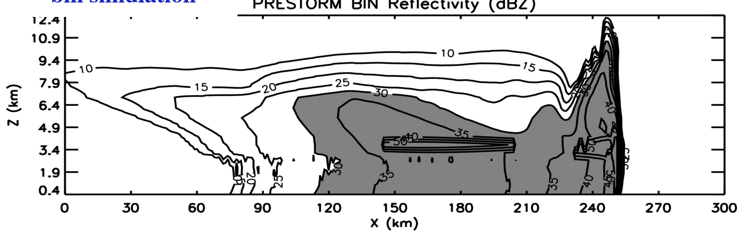
More than 10 Universities have used the GCE model
~ 140 papers published based on GCE model

Improving the Simulation of Convective Cloud Systems: higher resolution and improved ice physics

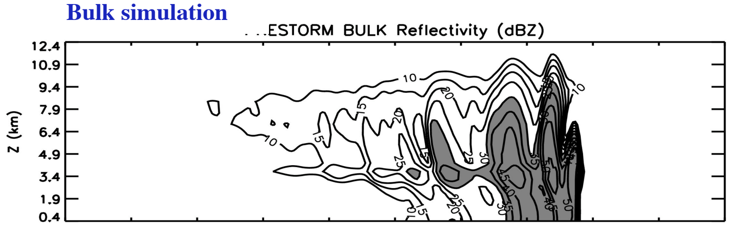
Observation

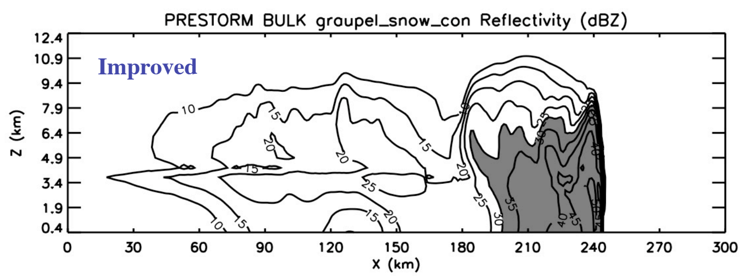


bin simulation

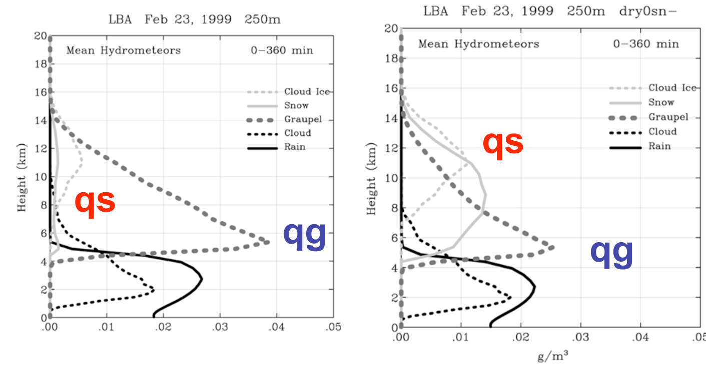


Bulk simulation



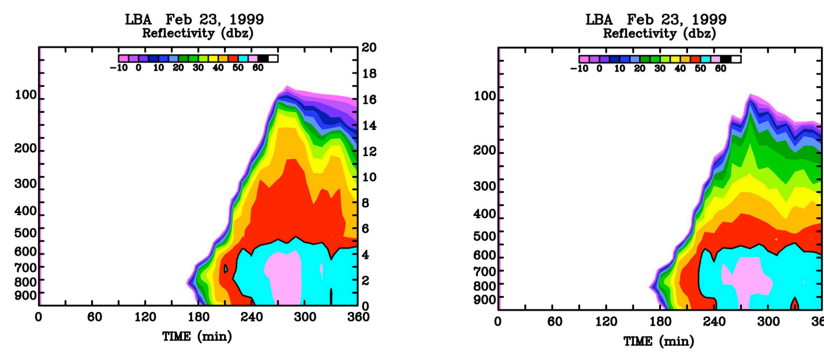


Reducing rain evaporation using empirical formula derived from model simulations (Li et al. 2009, JAS).



Lang *et al.* (2007, MWR): 3ice-graupel WRF3.1

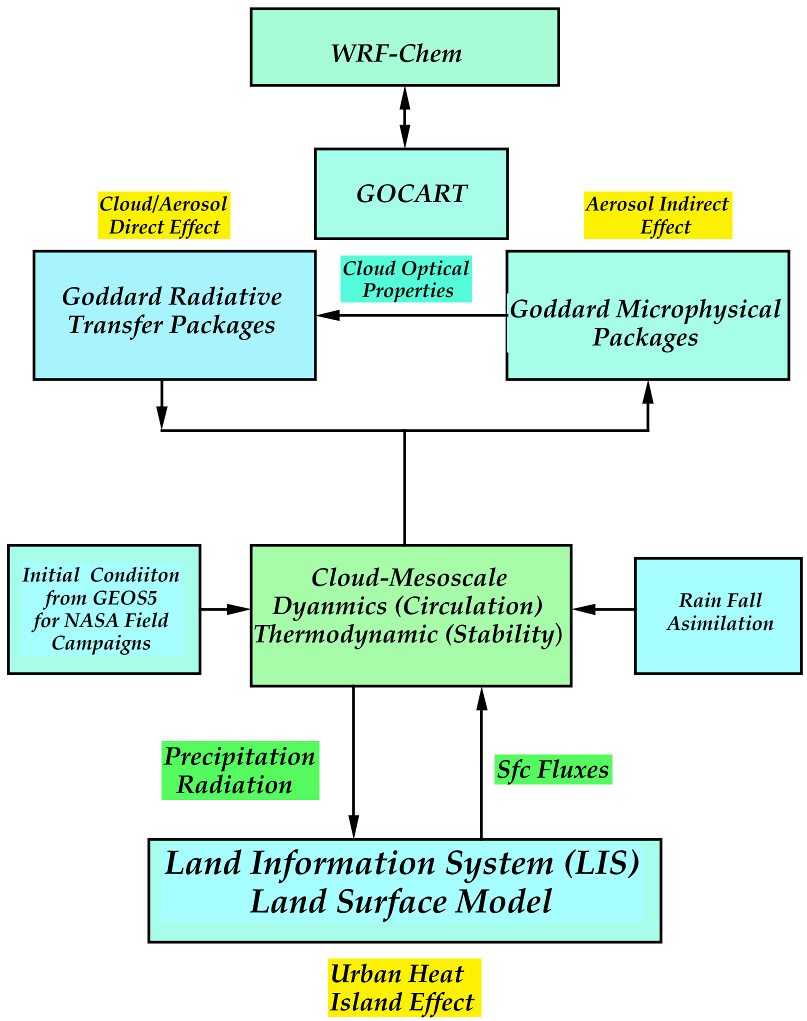
Climatologically, 40-dBZ penetrations above 10 km are rare even over land
(Zipser *et al.* 2006)



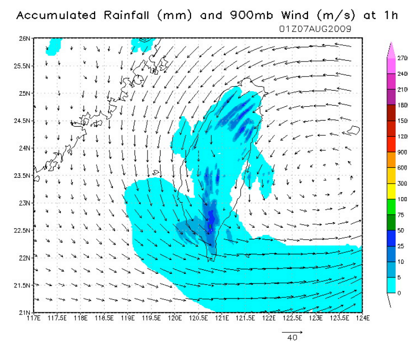
Lang *et al.* (2009, MWR): 3ice-graupel Goddard WRF3.1

NASA Unified WRF (Physics)

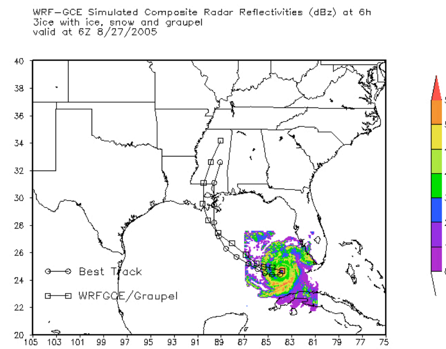
Peters-Lidard, Tao, M. Chen



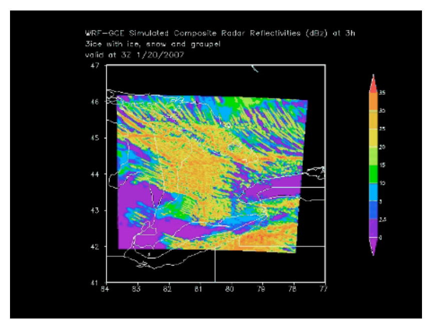
Blue Boxes:
NASA Physical Packages



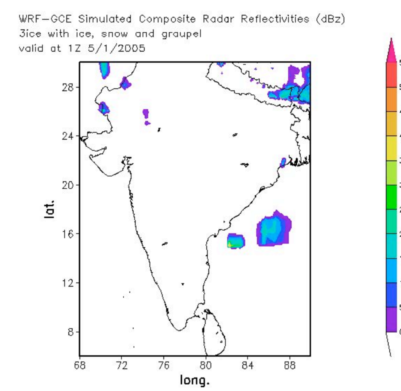
Typhoon Karokot



Hurricane



Snow (C3VP)



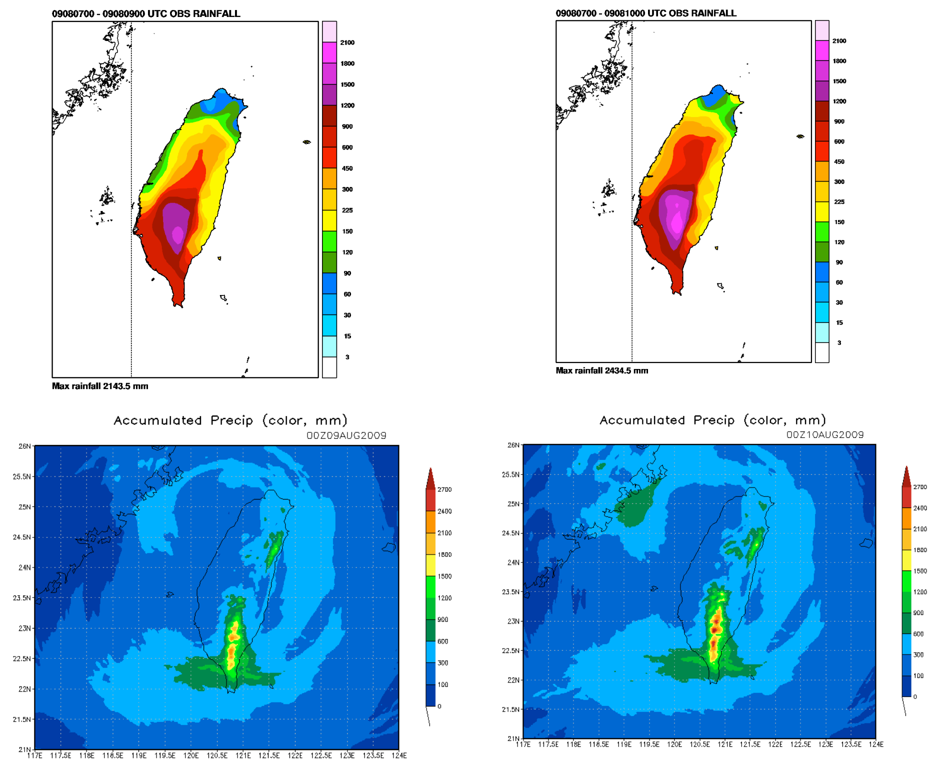
Indian Monsoon

Improved Goddard Microphysics for simulating a 2000 mm rainfall associated with a Typhoon that is the worst flooding in 50 years in Taiwan

Typhoon Morakot struck Taiwan on the night of Friday August 7th, 2009 as a category 2 storm with sustained winds of 85 knots (92 mph). Although the center made landfall in Hualien county along the central east coast of Taiwan and passed over the central northern part of the island, it was southern Taiwan that received the worst effects of the storm where locally as much as **2000 mm (2 m) of rain** were reported, resulting **in the worst flooding there in 50 years.** The result of the enormous amount of rain has been massive flooding and devastating mudslides. **More than 600 people are confirmed dead.**

High-resolution (2-km) WRF with improved Goddard microphysics will be used for simulate this typhoon case. The improved microphysical scheme captured both in terms of maximum rainfall area and intensity (left figures and table). The model also found that the **heavy amounts of rain over the southern portion of the island is due to persistent southwesterly flow associated with Morakot and it's circulation was able to draw up copious amounts of moisture from the South China Sea into southern Taiwan where it was able to interact with the steep topography**.

In addition, we are in the process to produce model results with high resolution visualization (2 km and 2 minutes) including tracer and trajectory.



Observed and WRF simulated accumulated surface rainfall (mm). The top two panels are the observed 48- (left) and 72-h (right) observed rainfall (based on dense rain gauge network). The bottom two panels are with 2 km grid spacing with improved microphysics at corresponding 48- (left) and 72- h (right) WRF simulations.

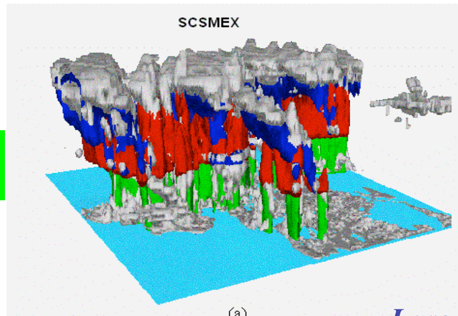
Microphysical schemes	48 – hours Maximum Rainfall (mm)	72-hours Maximum Rainfall
3ICE-Hail with reduced Evaporation	**2867**	**3307**
3ICE-Graupel	**2856**	**3345**
3ICE – Graupel Improved	**2396**	**2942**
Observation	**2134**	**2434**

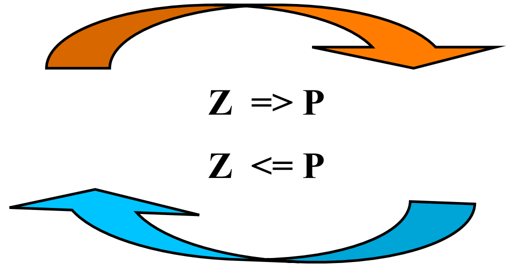
The maximum rainfall simulated by model with different Goddard microphysical options. Observed maximum rainfall is also shown for comparison.

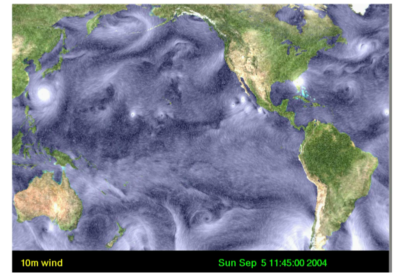
NASA Goddard MMF

Moist physics tendencies (T and q) Cloud and precipitation

GCE







fvGCM

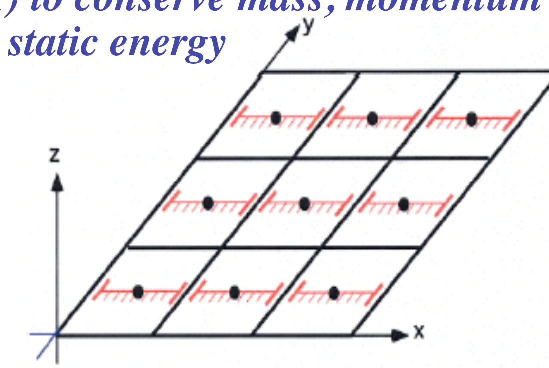
Large-scale forcing, Background profiles (T, q, u, v, w)

NASA MMF
Goddard fvGCM – GCE Model
2 x 2.5 degree (*13,104 CRMs*)
Microphysics (>40 processes)
Positive definite advection scheme
1.5 order TKE
Radiation (every 3 min)
Time step (10 s)
32 vertical layers (32 in fvGCM)
V – Component (no PGF)
Online cloud statistics (every 2 min)
278 hours/per simulated year on a 512 CPU computer

2D GCE has 64 x 32 (x-z) grid points with 4 km horizontal resolution

fvGCM and GCE coupling time is one hour

Interpolation between hybrid P (fvGCM) and Z (GCE) coordinate: using finite-volume Piecewise Parabolic Mapping (PPM) to conserve mass, momentum and moist static energy

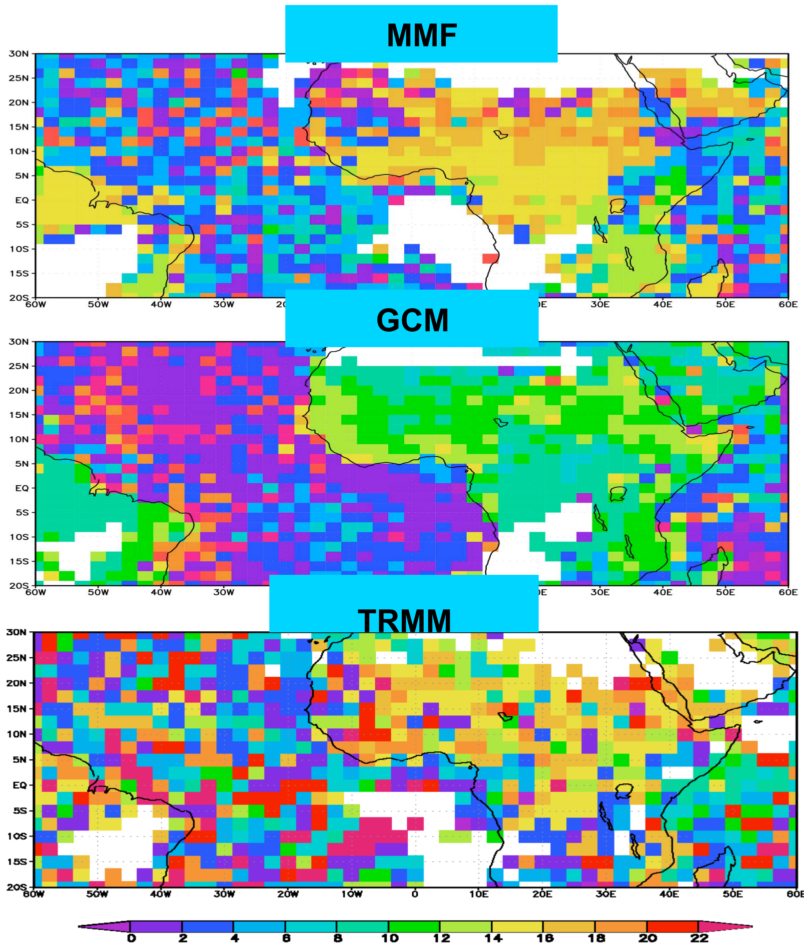


Tao, W.-K., J. Chern, R. Atlas, D. Randall, X. Lin, M. Khairoutdinov, J._L. Li, D. E. Waliser, A. Hou, C. Peters-Lidard, W. Lau,J. Jiang and J. Simpson, 2009: Multi-scale modeling system: Development, applications and critical issues, *Bull. Amer. Meteor. Soc.* **90**, 515-534.

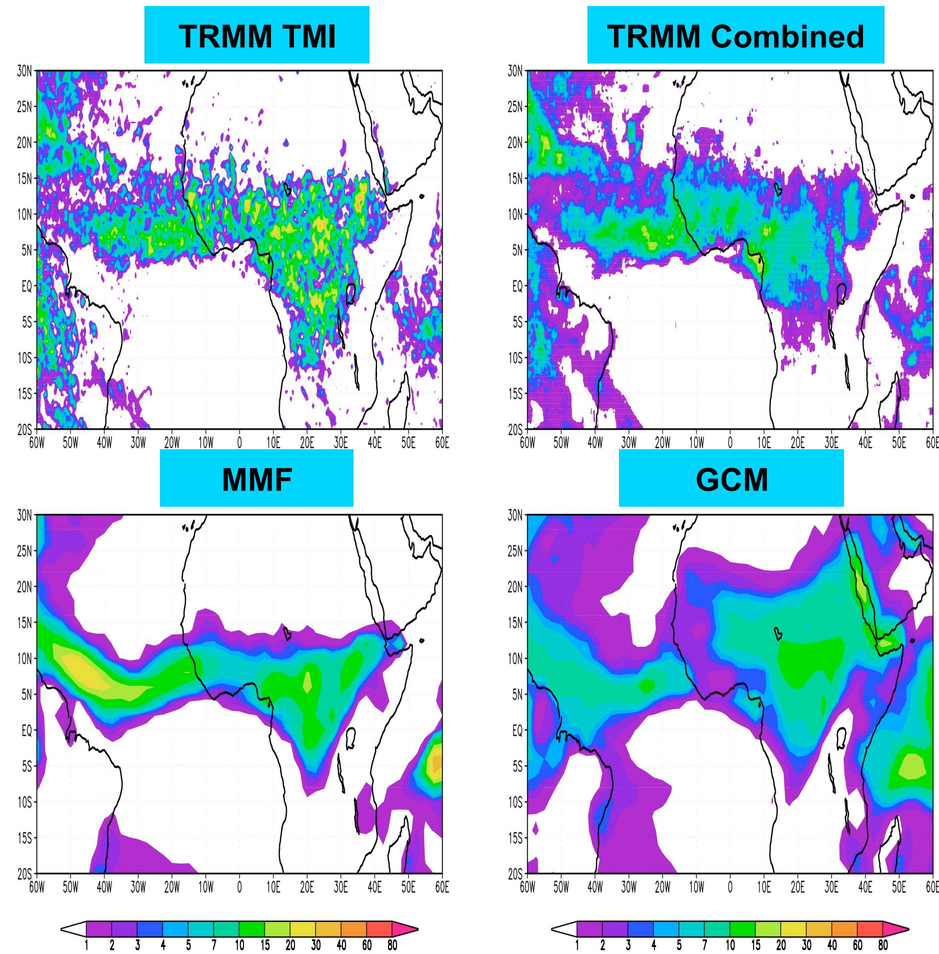
Monthly precipitation and local time of precipitation frequency maximum over West Africa

MMF captured satellite observed surface precipitation and its diurnal variation.

The results imply that the MMF could be used to study local and regional surface water/energy cycle



Geographical distribution of the local solar time (LST) of non-drizzle precipitation frequency maximum over West Africa in summer 1999 as simulated with the Goddard MMF (upper panel) and the GCM (middle panel) and as observed by the TRMM TMI (bottom panel). Blank regions indicate no precipitation.

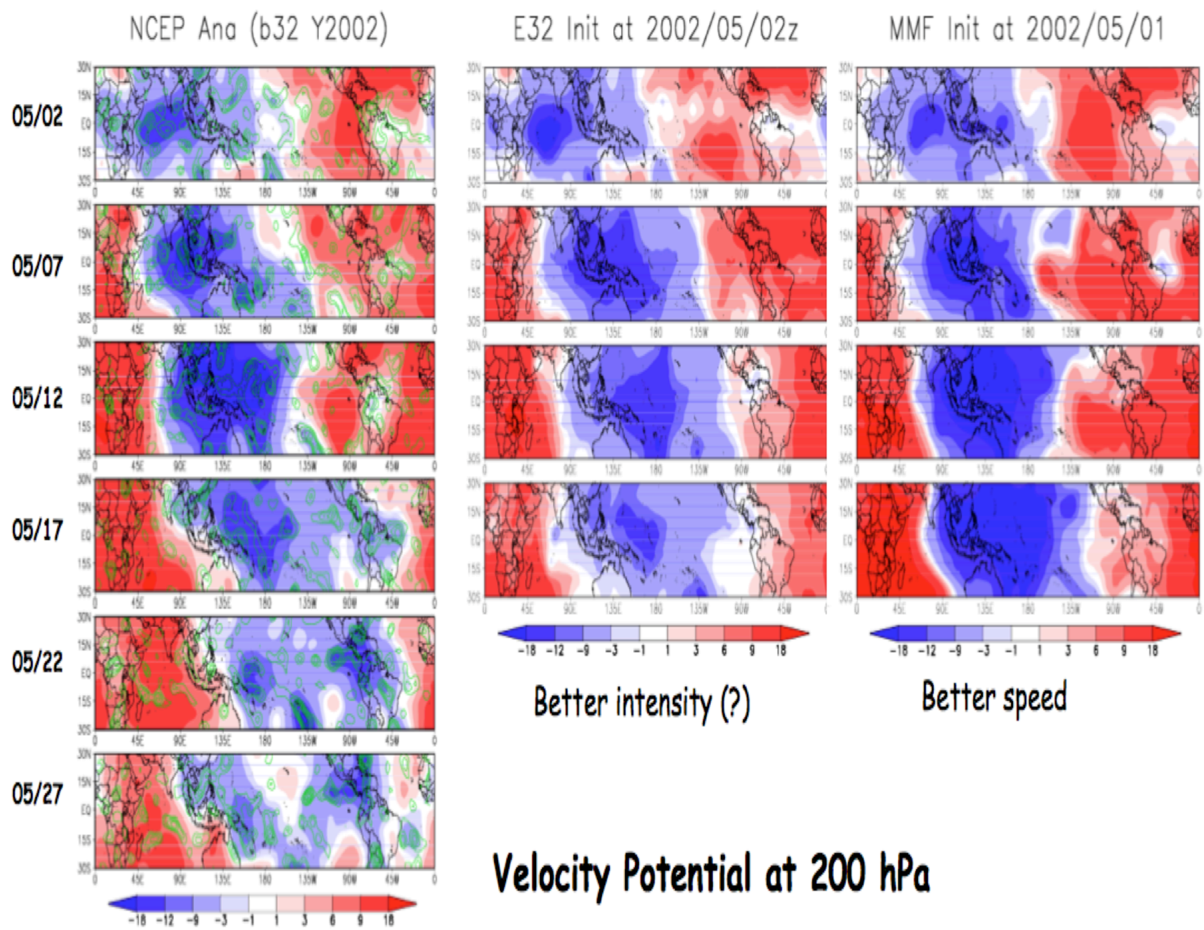


Monthly precipitation rates (mm/day) over West Africa for September 1999 from TRMM observations (TMI, top-left, and Combined, top-right) and simulations from the Goddard MMF (lower-left panel) and the GCM (lower-right panel).

Utilize high resolution GCM and MMF for study the impact weather event (MJO)

The Goddard MMF based on the coupling of fvGCM and 2D GCE models has been successfully applied to long term climate studies (such as AMIP type simulations, climate change simulations), interannual variability (such as El Nino and La Nina simulations), interseasonal and seasonal variability (such as Madden-Julian Oscillation, Africa Easterly waves, draught and flood, tropical cyclones), and short-term weather events and diurnal cycle studies.

To fully understand the strengths and weakness of the MMF approach in climate modeling, the simulation results have been compared rigorously against the results from fvGCM AMIP run, NCEP and ECMWF analysis, and NASA high resolution satellite observations such the Tropical Rainfall Measuring Mission (TRMM), the Moderate Resolution Imaging Spectroradiometer (MODIS), Microwave Limb Sounder (MLS), and the CloudSat.



Velocity potential at 200 hPa every 5 days in May 2002 from NCEP analysis (left panels), 15-day fvGCM model predictions at 1/8 degree resolution (middle panels), and 15-day fvMMF model predictions (right panel). **The velocity potential plots showed the observed and predicted patterns and propagations of Madden-Julian Oscillation (MJO). The high-resolution fvGCM is able to reproduce realistically the observed patters and intensity as NCEP analysis. The fvMMF even with coarse-resolution (2° x 2.5°) is also able to predict the large-scale MJO event, except its intensity is somewhat overestimated**

J. Chern, B.-W. Shen, Tao, C. Perters-Lidard

Use high-resolution satellite observation to evaluate and advance NASA modeling ability for weather and short-term climate

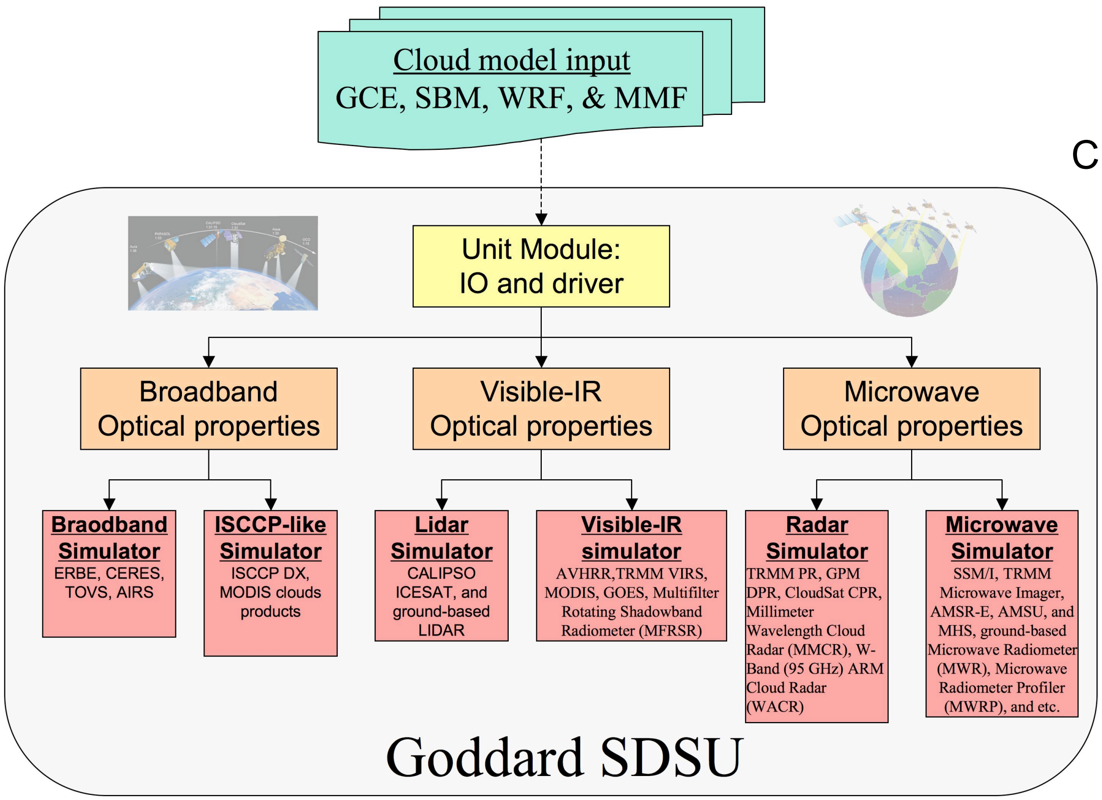
PI: Wei-Kuo Tao
Co-Is: **J. Chern**, T. Matsui, **B.-W. Shen**, J. Bacmeister, M. Suarez, A. Hou, W. Lau, and **C. Peters- Lidard**
Collaborators: M. Rienecker (GMAO), C. Zhang (University of Miami), D. Waliser (JPL), G. Stephen (CSU), S. Lang (SSAI), and X. Li (GEST).

	Period/Case	GCM	CRM	Satellite data
Task 2 and Task 3.1				
Exp. 1a	1988-2007	GEOS-5	2D	Precipitation (TMPA, TRMM, AMSR-E) Cloud top pressure and optical depth (ISCCP, Aqua/Terra MODIS) Radiance data (TRMM, CloudSat, Aqua AMSR-E) Near-surface wind speed (QuickSCAT)
Exp. 1b	2006-2007	GEOS-5's replay mode	2D	
Exp. 2	1998-2008	GEOS-4	2D	
Exp. 3	1998-1999 and 2006-2007	GEOS-4	**3D (8 x 8 grid points)**	
Exp. 4	Seasonal	GEOS-5	3D for targeted region, 2D elsewhere	
Exp. 5	Seasonal	GEOS-5	3D for targeted region, no 2D elsewhere	
Monthly – Seasonal – MJO (Task 3.2)				
Exp. 6	Monthly-Seasonal (December 2006)	GEOS-4	2D/3D	Precipitation (TMPA, TRMM, AMSR-E) Cloud-top pressure and optical depth (ISCCP, Aqua/Terra MODIS) Condensate profiles (TRMM, CloudSat, Aura MLS) Latent heating profiles (TRMM CSH and SLH) Temperature and water vapor profiles (Aqua AIRS) TOA and surface energy budget (CERES)
Exp. 7	Monthly-Seasonal (May 2002)	GEOS-4	2D/3D	
Exp. 8	Monthly-Seasonal (December 2006)	GEOS-5	2D/3D	
Exp. 9	Monthly-Seasonal (May 2002)	GEOS-5	2D/3D	
Microphysics (Task 1)				
Exp. 10	ARM, TWPICE, PRESTORM		2D, 3D (4k, 1km, and 250m horizontal grid spacing)	Radiance data (TRMM, CloudSat, Aqua AMSR)
Exp. 11	Seasonal (JJAS) 2005, 2006 and 2007 $1^{o} \times 1.25^{o}$	GEOS-4	2D	

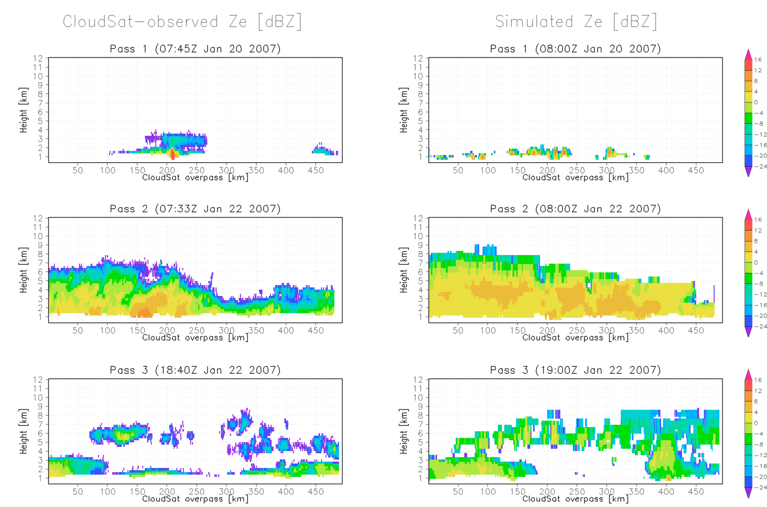
YOTC (3 monthly experiments): Initial condition (MERRA and NCAR/NCEP)

May 20 - June 20 2008; January 15 - February 15, 2009; April 1 - May 1 2009

Goddard Satellite Data Simulation Unit (SDSU) for evaluating models' performance and supporting NASA's satellite missions



CloudSat-observed and WRF-simulated *Ze*



Examine an evaluation method for Goddard multi-scale modeling system by using direct measurements from space-born, airborne, and ground-based remote sensing.

Support the NASA's satellite mission (e.g., A-Train, GPM and ACE) through providing the virtual satellite measurements as well as simulated geophysical parameters to satellite algorithm developers.

Masunaga, H., Matsui, T., W.-K. Tao, A. Y. Hou, C. Kummerow, T. Nakajima, P. Bauer, W. Olson, M. Sekiguchi, and T. Y. Nakajima, 2009: Satellite Data Simulation Unit: Multi-Sensor and Multi–Frequency Satellite Simulator package, *Bulletin of American Meteorological Society*, (submitted).

Current - Future Model Improvements (NEWS, MAP and PMM)

To utilize the satellite simulator to identify the strengths and weaknesses of model-simulated microphysical processes

- Model Improvements

  Complete the MMF and LIS coupling to study interaction between cloud systems and land surface processes

  Complete the MERRA and CRM/SCM coupling

  Implement an improved microphysics in CRM that is embedded within MMF

  Investigate the impact of terrain effect on MMF's performance

  Couple with 3D GCE MPI, GEOS5, an ocean mixed model, and an Non-hydrostatic GCM

  Improve the MMF cloud dynamics and test many different MMF configurations

  Couple the MMF model with the Satellite Data Simulation Unit (SDSU) to identify the strengths and weaknesses of the model microphysical processes.

- Scientific Applications

  Conduct 11-year (1998-2008) MMF integrations and examine the physical processes associated with diurnal variation of cloud/precipitation over land

  Examine the explicit direct and indirect cloud-aerosol-radiation interactions (GOCART)

  Investigate the flood/draught and (land fall) hurricane events in USA

  Investigate the impact of surface processes on weather/climate events in local, regional scale

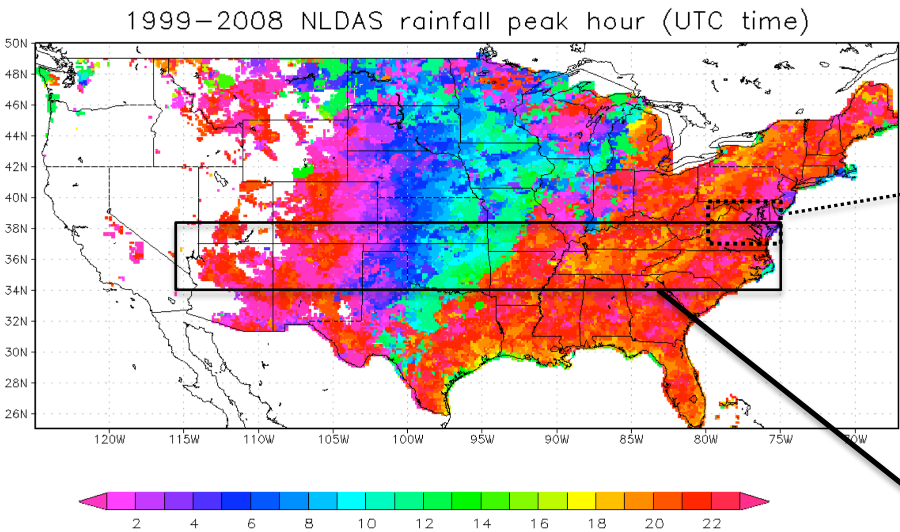
- MMF (1998, 1999, May 2005 to September 2007), WRF and GCE cloud data is current available through Goddard web site:

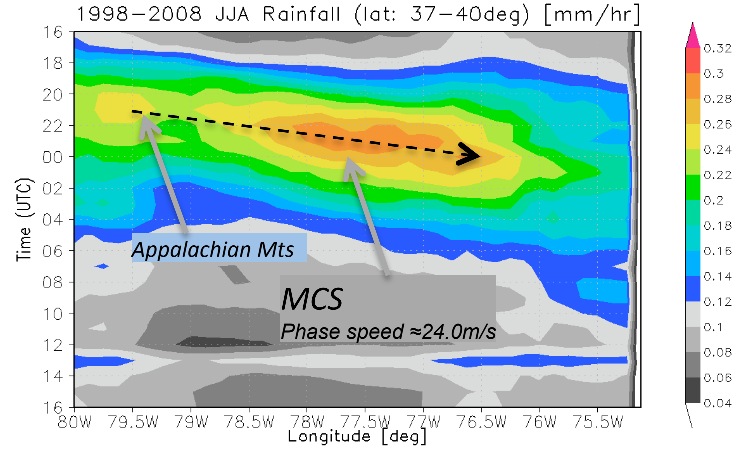
  Website for mesoscale modeling group and cloud library

  http://portal.nccs.nasa.gov/cloudlibrary/index2.html

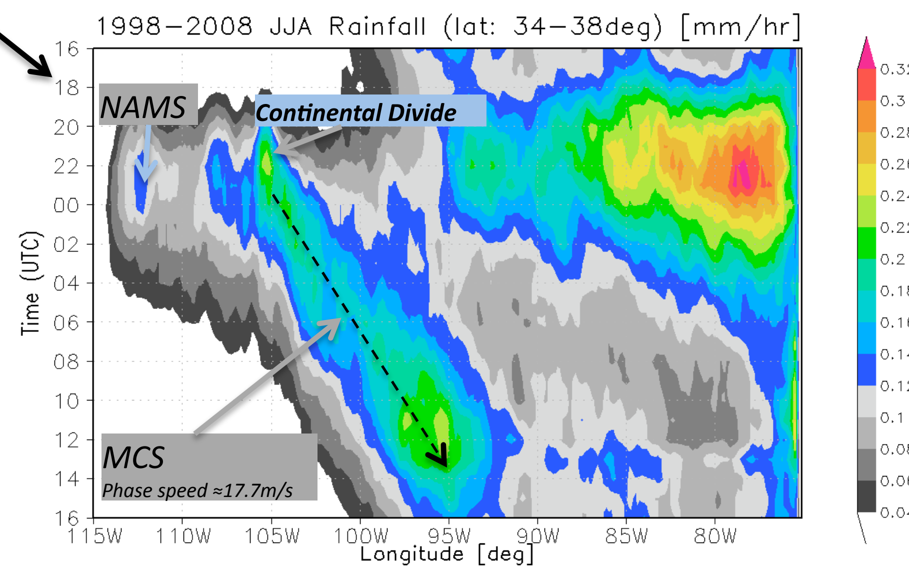
U.S. Diurnal Rainfall Climatology Map (JJA 1998~2008)

Masked out dry region (<0.1mm/hr)





Hovmöller diagrams



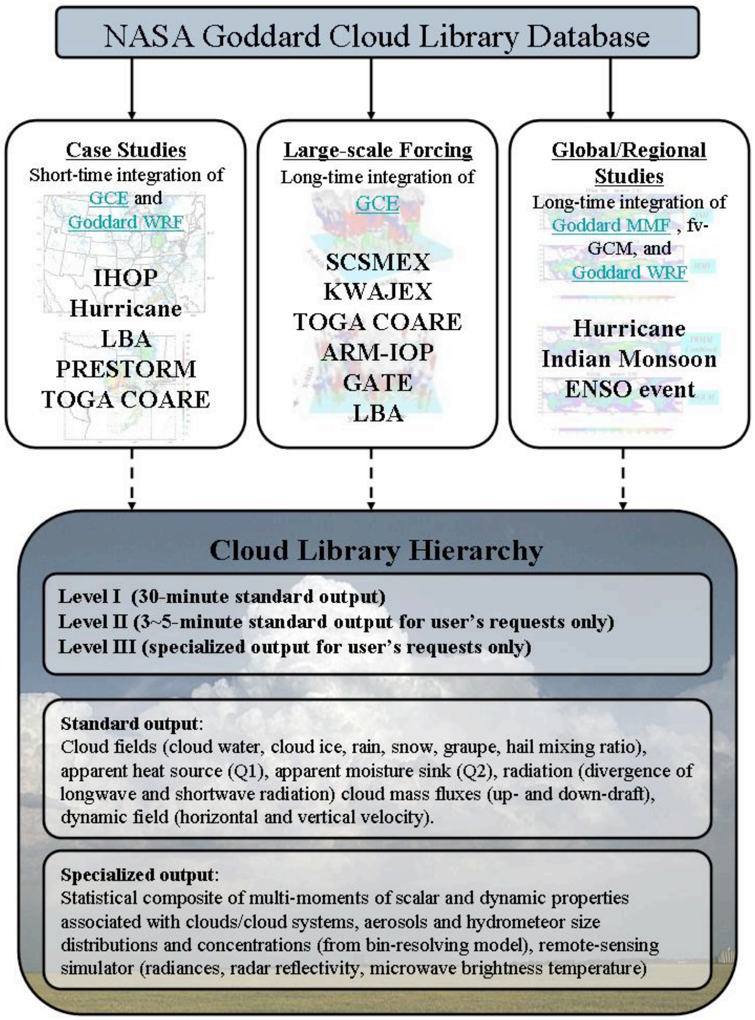
Objectives

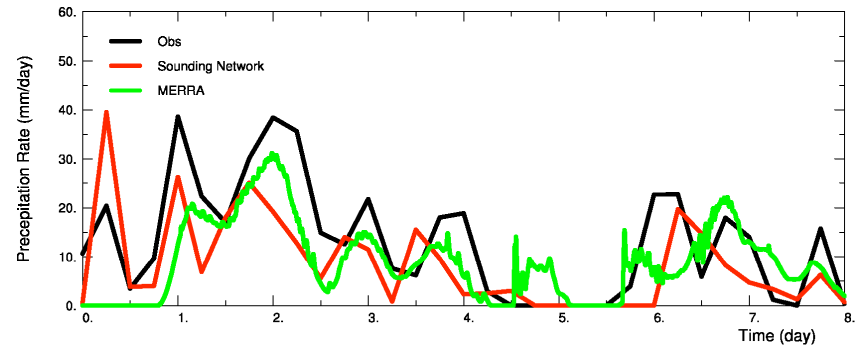
- Understand climatology of US warm-season rainfall diurnal cycle using NLDAS rainfall data.
- Examine eastward propagating mesoscale convective system (MCSs).

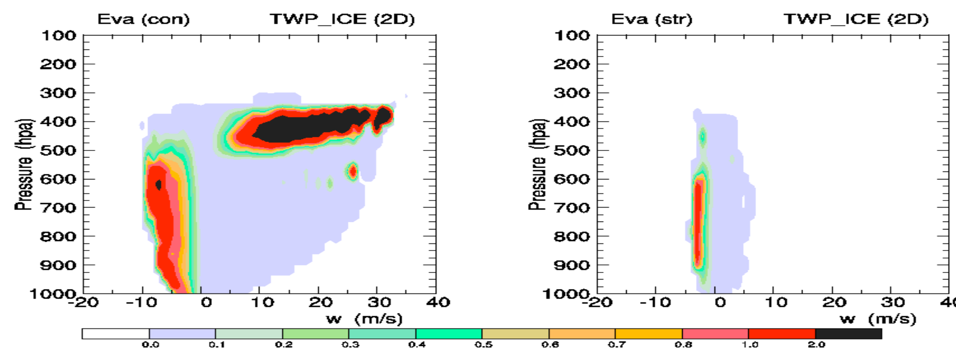
Results

- MCSs dominate diurnal cycle of rainfall across the Great Plain, while local afternoon parcel lift typically dominate rainfall diurnal cycle in the other regions.
- Propagation speed of MCSs in Maryland is about 6m/s faster than those in Great Plain.

Matsui, T., M.-I. Lee, J.-D. Chern, D. Mocko, and W.-K. Tao (2009), 10-year Climatology of the Diurnal Cycle in Summertime Rainfall Over the Conterminous U.S. (to be submitted to GRL)



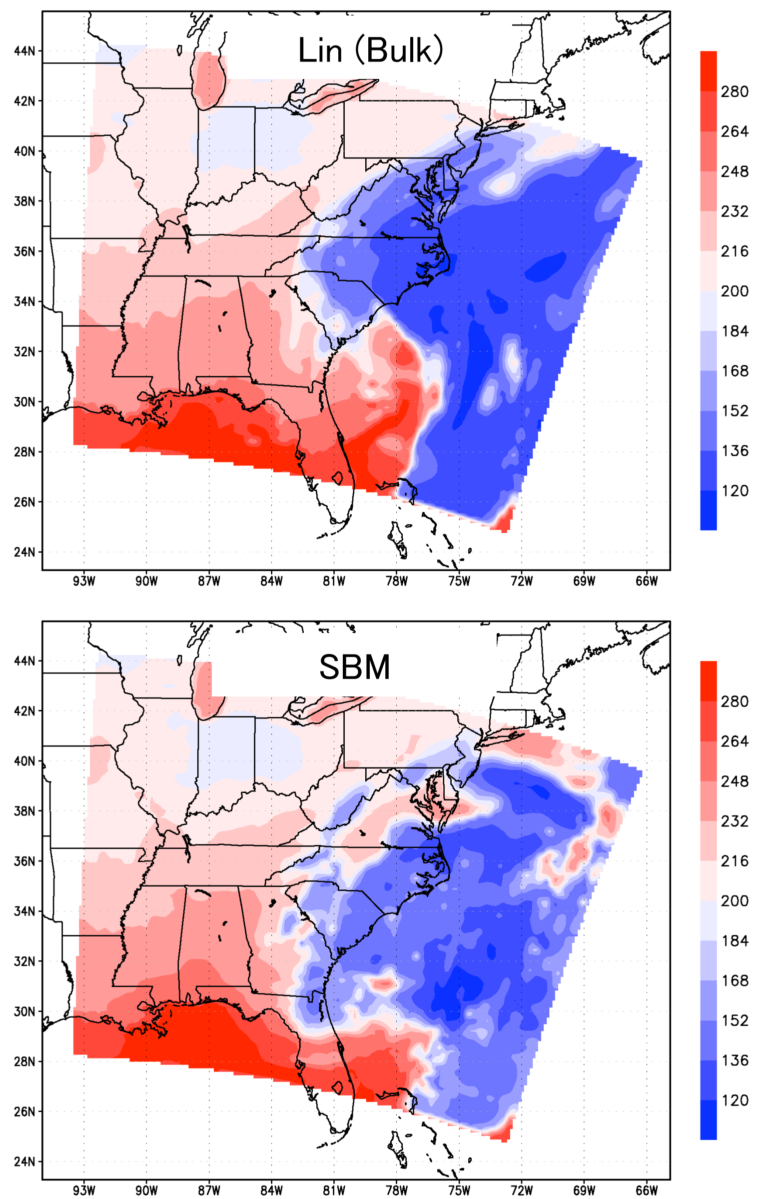




CFAD: Relate the microphysics (i.e., condensation/ deposition) and dynamics (w-velocity)

WRF-SBM: the East Coast Winter Storm of January 24-25, 2000

OLR W/m^2 00UTC 25 Jan. 2000

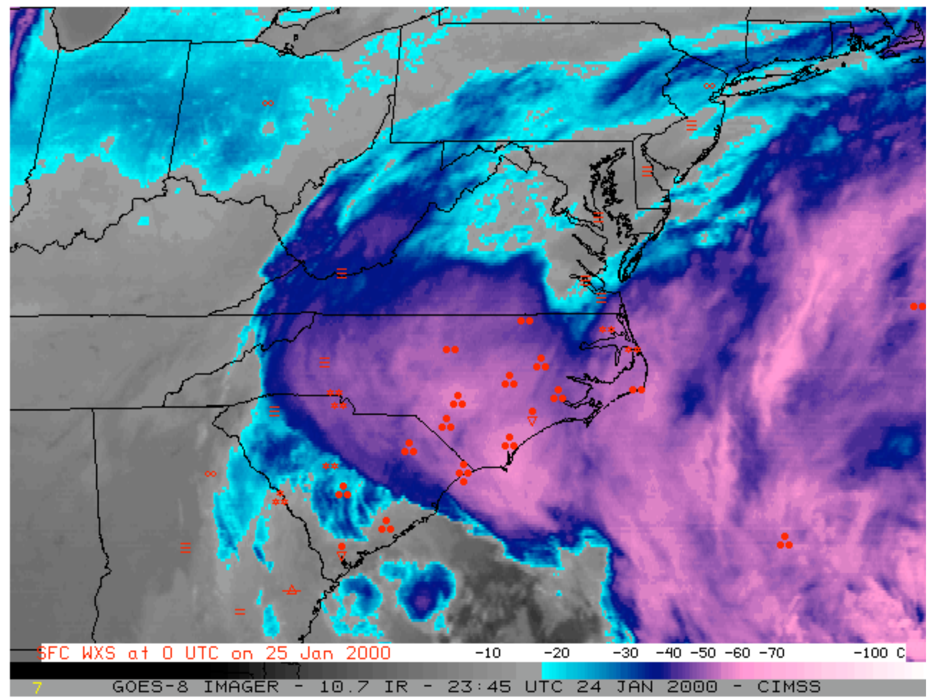


GrADS: COLA/IGES

2009-10-26-16:52

SBM: Spectral Bin Microphysics

GOES8 IR image



Both simulations reasonably reproduce distribution of developed clouds system shown by the satellite observation.

The simulation with SBM replicates a complex structure of the clouds better.